STUDIES ON CHEMICAL CHANGES DURING THE LIFE CYCLE OF THE TENT CATERPILLAR (MALACOSOMA AMERICANA FAB.) IV. GLYCOGEN[1]

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Glycogen is an important constituent of muscle. The glycogen content of muscle varies and is greatly decreased by intense muscular activity. In men and herbivorous animals the liver stores the reserve supply of this "annual starch" and transforms it into glucose (called also grape sugar or starch sugar). The glucose is passed into the blood stream and so carried to the working muscle. Here the sugar is synthesized into glycogen and the glycogen thus formed is then changed into glucose whenever the working muscle may need it. The stored up glycogen is thus potential fuel for the muscles, but it must be changed to sugars before it can be used. Examination of living muscle shows granules, which may be glycogen.

The formation of polysaccharides (starch, cellulose, glycogen, gums, inulin, etc.) from monosaccharides (sugars) is probably an attribute of all living matter. The transformation apparently takes place very easily. We do not know, however, how this transformation is produced in living matter, although we can simulate the processes with chemicals in the laboratory. We know that in animal tissue synthesis of glycogen from glucose does not take place when a living cell is anesthetized and some investigators think that the respiration of the cell is in some way involved in the condensation of glucose into glycogen.

The amount of glycogen in different muscles and in the corresponding muscles of different animals is variable. Horse muscle, for instance, contains an unusually large quantity of glycogen, 1 to 2 per cent., and since glycogen can be detected in muscle microscopically by the brown reaction it gives with iodine, the

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presence of horse meat in sausages or other meat products can easily be determined. Another muscle containing large amounts of glycogen is that of the scallop, about 1.5 per cent., while ox flesh and other forms of muscle contain less. The glycogen content of muscles is subject to variation with the diet, but the variation is less than that of liver glycogen. In fasting glycogen disappears rapidly, while a large intake of glucose or other carbohydrates increases the glycogen content of both liver and muscles. The glycogen of muscle undergoes a rapid decomposition after death, and in beef which has hung for some time the amount of glycogen is much reduced. In hen's muscle 30 to 60 minutes after death 25–28 per cent. of the glycogen is lost and the reduction of glycogen in rabbit's muscle may after a few hours be as much as 90 per cent.

Certain substances and poisons cause a disappearance of glycogen in muscle. For instance, it has been found that arsenic causes the glycogen to disappear from the muscles of a cat. It would be very interesting to know what changes take place when arsenicals were administered to insects and the results would probably be very illuminating.

Methods and Material

The material used has been described in a previous paper (2). The glycogen was determined according to the official methods of the Association of Official Agricultural Chemists by boiling a quantity of material with water, treating it with alcohol and acidification with HCl. The final solution, containing the glycogen is neutralized with NaOH and reducing sugars determined in the regular way. The results obtained have been expressed as glycogen.

Results

The results secured are graphically shown in Figure 1. The amount of glycogen in the egg masses was small, namely 0.28 per cent. on a dry basis. No decrease in glycogen took place during the first stage when the larvae were formed. The amount of glycogen remained constant as far as the total egg masses were concerned. During the winter the glycogen decreased gradually. The frothy covers of the newly laid egg

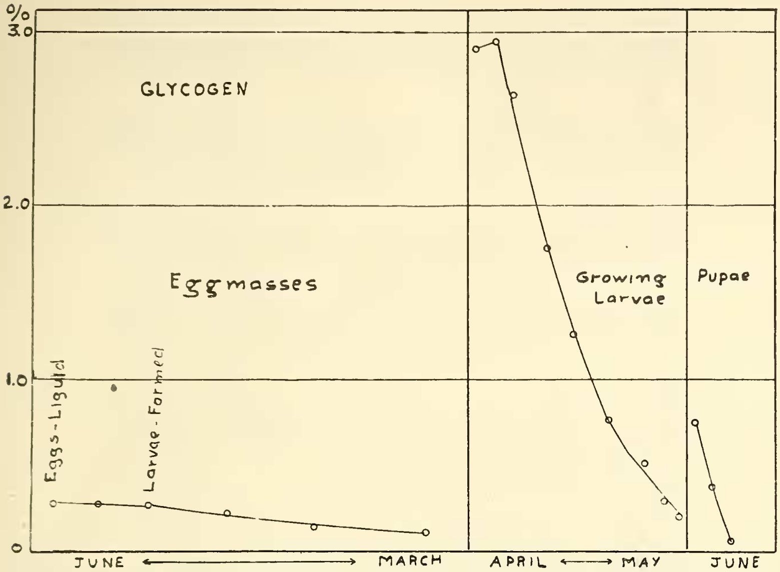

Fig. 1. Percentage glycogen present during the life cycle of the caterpillar.

masses contained nearly twice the amount of glycogen as the whole mass. Upon hatching the larvae contained 2.79 per cent. glycogen, which increased somewhat during the next few days and thereafter decreased rapidly until but little was left. This is in accordance with the findings of Vaney and Maignon (4) who studied the variations in glycogen occurring in the cocoons of the silkworm (*Bombyx mori*). Their detailed results are of interest and are therefore graphically shown in Figure 2. Unfortunately their results are expressed on the basis of wet weights of the insects and the moisture contents are not known. The silkworm cocoon has apparently much greater glycogen contents than the tent caterpillar ever amassed in any stage of its life cycle. If we assume that after eight days the cocoons of Vaney and Maignon had a percentage moisture of 75 per cent., the total glycogen on a dry basis would have been on that day not less than 6.0 per cent. The fluctuations in the curve might have been due to some extent to the variation in moisture content but the uniform reduction in weight of the cocoons suggest that

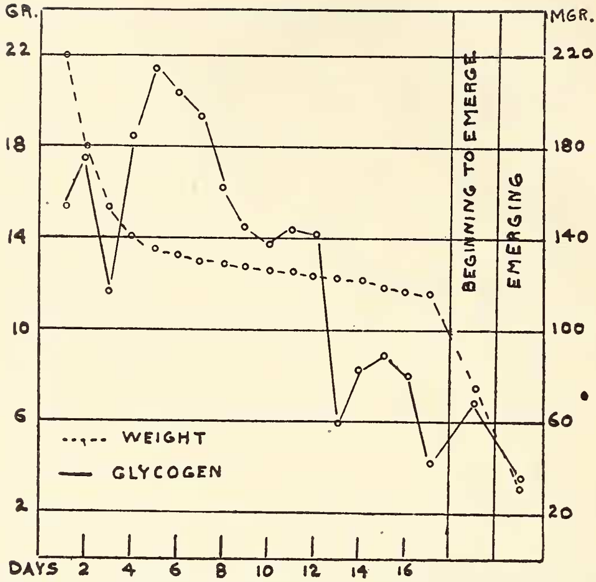

Fig. 2. Weight and amount of glycogen present in 10 nude cocoons of the silkworm.

the rapid decrease in glycogen after the fifth day was due to a consumption of glycogen. Shinoda (3) working with the wild silk moth (*Dictyoploca japonica*) found that the water soluble reducing sugars increased during the first few days when the larvæ were growing, but decreased rapidly thereafter. He found only traces of glycogen in the pupæ, although he had expected to find measurable quantities.

It is of decided interest to compare the changes in fat content with the changes in glycogen observed during the life cycle of the caterpillars (Fig. 3). The reduction of fats of the egg masses runs parallel with the reduction of glycogen, but in the growing larvæ fat accumulation took place whereas the glycogen per gram dry weight decreased in approximately the same ratio. This does not mean that the absolute fat increase was the same as the absolute glycogen decrease, but the rates of accumulation and disappearance were the same.

Since glycogen may be considered as important for muscle activity it is logical that the glycogen did not increase in the

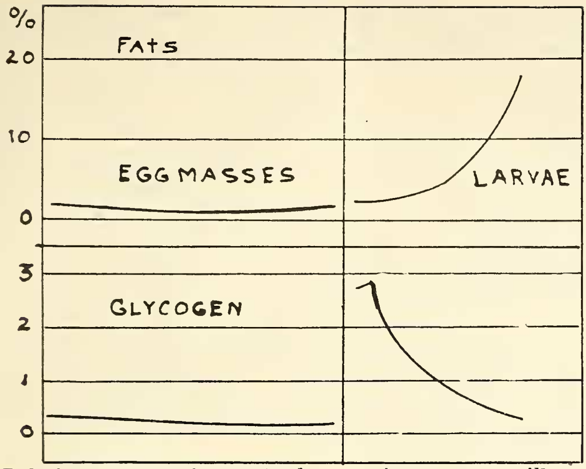

Fig. 3. Relation between fats and glycogen in tent caterpillars.

growing larvæ in relation to their growth, but the percentage decreased. However, the total amount of glycogen present in larvæ just after hatching was considerably less as compared with the total weight in the full grown larvæ. The wet and dry weight of larvæ upon hatching and of full grown larvæ, together with the amounts of glycogen present are given in table 1.

TABLE 1

RELATION BETWEEN WEIGHT OF LARVÆ AND AMOUNT OF GLYCOGEN

Age	Weight of 100 larvæ		Glycogen in 100 larvæ (dry)
	Wet	Dry	
	gr.	gr.	mgr.
Newly hatched	3.0	1.0	27.9
Full grown	642.0	50.7	375.0

The full grown larvæ contained actually 13 times more glycogen than the newly hatched, but their weight had increased at least 210 times. It is clear therefore that glycogen accumulation took place in order to supply the increased demand of muscle activity.

Glycogen transformation seems to be important in relation to the sex of the insect. Vaney and Maignon (4) made a study of the glycogen content of silk worm moths. Their results are of sufficient interest to be given here (table 2).

TABLE 2
DIFFERENCE IN PERCENTAGE GLYCOGEN OF MALES AND FEMALES

	Males	Females
Chrysalids (17 days)	0.755	0.636
Adults copulating	0.420	1.229
Adults after copulation and at play	0.888	1.300

It will be seen that the differences between the chrysalids are but slight, although the males contained somewhat more glycogen. After copulation the females were much richer in glycogen than the males.

It would seem that different cells and muscles of the tent caterpillar adult are concerned with glycogen transformations. With the aid of the iodine and gentian-violet staining method the writer was able to determine considerable quantities of glycogen in the leucocytes, muscles and the fat glands. The eggs present in the body of the female seemed also to contain glycogen, which indicates that during the transformation of the liquid egg to the larvæ possibly but little of the stored up glycogen was used. During this transformation the fats decreased appreciably which might mean that fats play during this particular part of the life cycle a more important rôle than glycogen.

When muscles are very active there is a great diminution in glycogen content of the muscle. Glycogen is used up and the energy for the work may come therefore from the glycogen. The question is whether this glycogen is the only source of the energy. The amounts of glycogen in the body are small and it would seem that the glycogen present would soon be used up. Naturally, the glycogen can quickly be reformed, but since fats first increase and later decrease during the pupation processes and the glycogen content changes in a similar fashion, it is either possible that fats as such are used or that they are partially decomposed and resynthesized into glycogen.

Arsenic causes the disappearance of glycogen, while Arnold (1) states that glycogen is best fixed by mercuric chloride containing some glucose. It may be possible that such facts can be utilized in insect control when we know more about the chemistry and physiology of insects.

SUMMARY

The glycogen content of the apple tent caterpillar changes during the different phases of its life cycle. The greatest changes take place when the larva is actively feeding and although the percentage of glycogen decreases in respect to the dry weight, the actual amount increases about 13 times. No great changes occur during the transformation of liquid eggs into larvæ. During the pupal stage the glycogen disappears, rapidly indicating that it plays an important rôle. Glycogen was found in the leucocytes, muscles, fat glands and eggs.

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